TIMING BASED SERVO WITH FIXED DISTANCES BETWEEN TRANSITIONS

DOCUMENTS INCORPORATED BY REFERENCE

Commonly assigned US Patent No. 5,689,384, Albrecht et al, is incorporated for its showing of a timing based servo system, 5 including a servo writer.

FIELD OF THE INVENTION

This invention relates to servo systems for laterally positioning data heads with respect to linear data storage media, such as magnetic tape, and, more particularly, to linear servo 10 track timing based servo patterns.

BACKGROUND OF THE INVENTION

Linear data storage media such as magnetic tape provides a means for physically storing data which may be archived or which may be stored in storage shelves of automated data storage 15 libraries and accessed when required. One method for maximizing the amount of data that can be stored is to maximize the number of parallel tracks on the media, and this is typically

accomplished by employing servo systems which provide track following and allow the tracks to be spaced very closely.

An example of track following servoing is the provision of prerecorded parallel longitudinal servo tracks that lie between 5 groups of longitudinal data tracks, so that one or more servo heads may read the servo tracks and an accompanying track following servo will adjust the lateral position of the head or the tape to maintain the servo heads at a desired lateral position with respect to the servo tracks such that the data 10 heads are centered with respect to the data tracks.

An example of a track following servo system comprises a timing based servo system of the incorporated U.S. Patent No. 5,689,384. A timing based servo system is employed, for example, with the Linear Tape Open (LTO) format, one example comprising 15 the IBM LTO Ultrium magnetic tape drive and associated tape cartridge. A linear servo track comprises a sensible transition pattern, for example, of prerecorded magnetic transitions forming a timing based servo pattern of a repeating cyclic periodic sequence of transitions of two different azimuthal orientations 20 that extend laterally over the linear servo track. For example, the pattern may comprise transitions slanted, or having an azimuthal orientation, in a first direction with respect to the direction of the linear servo track, alternating with transitions slanted, or having an azimuthal orientation, in the opposite

direction. Thus, as the medium is moved with respect to a servo read head in the linear direction, the lateral positioning of the servo read head with respect to the timing based servo track is sensed based on a measure of time between two transitions having

5 different azimuthal orientation as compared to time between two transitions having parallel azimuthal orientation. The relative timing of the transitions read by the servo read head varies linearly depending on the lateral position of the head. Thus, a number of parallel data tracks may be aligned with different

10 lateral positions across the servo track.

Synchronization of the servo read head and decoder to the servo pattern may be accomplished by having two separate sets of transitions, each set comprising a grouping of a different number of pairs of transitions, one set comprising a grouping having,

15 for example, 4 pairs of transitions, and another set comprising a grouping having 5 pairs of transitions. Thus, the lateral position of a servo read head with respect to the servo track may comprise a measure of time between two transitions having different azimuthal orientation, e.g., between the first

20 transition of a pair in one set and the other transition of the pair, this distance called the "A" distance; as compared to time between two transitions having parallel azimuthal orientation, e.g., between the first transition of a pair in one set and a

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similar first transition of another pair in another set, called the "B" distance.

The prior linear servo track timing based servo pattern is generated by a servo writer having two spaced apart write

5 elements of different azimuthal orientations, forming the "A" distance. A drive moves the linear data storage medium across the write elements at a predetermined velocity, and a source of timed pulses causes the write elements to write a single pair of transitions for each pulse, such that the pattern of pairs of

10 transitions are written on the linear data storage medium.

In theory, the format is extendable to higher track pitches, wherein the data tracks are closer together. The "A" geometric distance is determined photolithographically, and is independent of the timing of the pulses or of the velocity of the servo

15 writer drive.

However, with the prior servo writer generator utilizing two spaced apart elements with different azimuthal orientations, the writer generator is pulsed periodically with the period between pulses set so that, with the nominal tape velocity of the servo

20 pattern writer, the geometric distance between patterns is the "B" distance mentioned above. Thus any error in the velocity of the tape in the servo writer results in an error in the "B" distance and hence an error in the lateral position calculated based on pulse "B" pulse timing assuming the correct "B"

distance. Hence, the precision of the "B" geometric distance between the first transition of a pair in one set and a similar first transition of another pair in another set, is dependent upon the precision of the velocity of the tape in the servo

5 writer drive and the precision of the timing between the pulses, so that the similar first transition of another pair in another set of transitions may be misregistered with respect to the first transition of the pair in the one set. Thus, with a given pulse timing, the distance between transitions determining the "B"

10 distance is strictly proportional to the velocity of the tape in the servo writer. Servo writer velocity error introduces a servo position error to the servo track following system and results in data track misregistration.

Further, the data track misregistration becomes worse for

15 data tracks that are positioned such that the distance between "A pulses is closer to the distance between "B" pulses.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a more precise linear servo track timing based servo pattern.

20 In one embodiment, a servo writer of the present invention generates a linear servo track timing based servo pattern in a linear direction on a linear data storage medium. The timing

based servo pattern remains comprised of a repeating cyclic periodic sequence of transitions of two different azimuthal orientations that extend laterally over the linear servo track, such that the timing based servo lateral position is determined 5 based on a measure of time between two transitions having different azimuthal orientation, e.g., the "A" distance, as compared to time between two transitions having parallel azimuthal orientation, e.g., the "B" distance.

With the present invention, the servo writer generator 10 comprises at least three spaced apart write elements, two of parallel azimuthal orientation, and at least one of a different azimuthal orientation than the two of parallel azimuthal orientation. Preferably, the write element of the different azimuthal orientation is located intermediate the two write 15 elements of parallel azimuthal orientation. A drive moves the linear data storage medium in the linear direction across the write elements; and a source of timed pulses causes the spaced apart write elements to simultaneously write.

The write elements write patterns on the linear data storage 20 medium corresponding to the spaced apart write elements, whereby the spaced apart write elements fix both the distance between transitions having different azimuthal orientation, the "A" distance, and the distance between transitions having parallel azimuthal orientation, the "B" distance, with photo lithographic

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precision independent of the velocity of the tape in the servo writer.

In further embodiments, the invention comprises the method of writing the servo pattern, the sensible transition pattern,

5 and the magnetic tape medium having prerecorded servo information recorded in magnetic transition patterns defining the linear servo track.

In one embodiment, in the repeating cyclic periodic sequence of transitions, the transitions having parallel azimuthal

10 orientation at one end of one pattern continue with the transitions having parallel azimuthal orientation at the opposite end of the next pattern, such that the continuing transitions are combined to have a different number of transitions than the remainder of the repeating cyclic periodic sequence of

15 transitions, thereby providing synchronization of the repeating cyclic periodic sequence of transitions.

In an alternative embodiment, with an even number of the write elements, the source of timed pulses provides a different number of the pulses for alternating sets of pulses provided to

20 the write elements. Thus, the sets of pulses write alternating patterns with different numbers of transitions, thereby providing synchronization of the repeating cyclic periodic sequence of transitions.

In a further alternative embodiment, the source of timed

pulses is coupled to two adjacent write elements and separately

coupled to the other write elements. The source of timed pulses

provides a first set of timed pulses to all of the spaced apart

5 write elements to simultaneously write to fix the distances

between both the "A" and "B" transitions, and additionally

provides at least one second timed pulse to only two adjacent

write elements to write different numbers of transitions within

the pattern, thereby providing synchronization of the repeating

10 cyclic periodic sequence of transitions.

For a fuller understanding of the present invention,

reference should be made to the following detailed description

taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

15   FIG. 1 is a diagrammatic illustration of a magnetic head and

servo control system of a magnetic tape drive, and an associated

magnetic tape having a servo track which may implement the

present invention;

FIG. 2 is a diagrammatic illustration of a servo head of the

20 tape head of FIG. 1 as it tracks a timing based servo pattern,

along with a representation of the head output signal and the

corresponding A and B signal intervals;

FIG. 3 is a diagrammatic illustration of a prior art arrangement of servo write elements;

FIG. 4 is a diagrammatic illustration of servo write elements arranged in accordance with one embodiment of the

5 present invention;

FIG. 5 is a diagrammatic illustration of servo write elements arranged in accordance with an alternative embodiment of the present invention;

FIGS. 6A and 6B are diagrammatic illustrations,

10 respectively, of a servo pattern written by the servo write elements of FIG. 4, and of a representation of a servo head output signal and the corresponding A and B signal intervals;

FIGS. 7A and 7B are diagrammatic illustrations, respectively, of a servo pattern written by the servo write

15 elements of FIG. 5, and of a representation of a servo head output signal and the corresponding A and B signal intervals;

FIGS. 8A and 8B are diagrammatic illustrations, respectively, of a servo pattern written by the servo write elements of FIG. 5, written in separate groups with separate

20 timing, and of a representation of a servo head output signal and the corresponding A and B signal intervals;

FIG. 9 is an illustration of a magnetic servo write head with servo write elements of FIG. 4;

FIG. **10** is a diagrammatic illustration of a servo writer for producing a servo track in accordance with the present invention;

FIG. **11** is a diagrammatic illustration of one embodiment of a servo pattern writer of the servo writer of FIG. **10** employing the servo write elements of FIG. **4** for producing the servo pattern of FIG. **6A**;

FIG. **12** is a diagrammatic illustration of one embodiment of a servo pattern writer of the servo writer of FIG. **10** employing the servo write elements of FIG. **5** for producing the servo pattern of FIG. **7A**;

FIG. **13** is a diagrammatic illustration of one embodiment of a servo pattern writer of the servo writer of FIG. **10** employing the servo write elements of FIG. **5** for producing the servo pattern of FIG. **8A**; and

FIG. **14** is a diagrammatic illustration of a tape drive storage device and an associated tape cartridge which may implement a servo track of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

This invention is described in preferred embodiments in the following description with reference to the Figures, in which like numbers represent the same or similar elements. While this

invention is described in terms of the best mode for achieving

this invention's objectives, it will be appreciated by those

skilled in the art that variations may be accomplished in view of

these teachings without deviating from the spirit or scope of the

5 invention.

Linear data storage media such as magnetic tape provides a

means for physically storing data which may be archived or which

may be stored in storage shelves of automated data storage

libraries and accessed when required. One method for maximizing

10 the amount of data that can be stored is to maximize the number

of parallel tracks on the media, and this is typically

accomplished by employing servo systems which provide track

following and allow the tracks to be spaced very closely.

Referring to FIG. **1**, an example of track following servoing

15 for linear data storage media such as magnetic tape **20** is the

provision of prerecorded parallel longitudinal servo tracks **27**

that lie between, or are offset from, groups of longitudinal data

tracks **29**. A head assembly **24** is shown in solid lines and

comprises a relatively narrow servo read head **26** that detects a

20 servo pattern recorded in the relatively wide servo track **27**.

The head assembly also comprises a data read head **28** positioned

over the data track region **29** and offset from the servo read

head. Although only a single servo read head and a single data

read head are shown, those skilled in the art will appreciate

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that most tape systems have multiple servo tracks, multiple servo read heads, and multiple data read and/or write heads.

As discussed in the incorporated U.S. Patent No. 5,689,384, the servo read head 26 has a width that is substantially less

5   than that of the servo track 27 and also that is less than one-half the width of a single data track, which is substantially narrower than a servo track. The servo track centerline 30 is indicated, extending along the length of the tape 20. The servo read head 26 reads the linear servo track timing based servo

10   pattern as the tape 20 is moved linearly with respect to the head, along the length of the servo track 27, and the servo read head generates an analog servo signal that is provided via a servo line 34 to a signal decoder 36. The signal decoder processes the servo read head signal and generates a position

15   signal that is delivered via a position signal line 38 to a servo controller 40. The servo controller generates a servo control signal and provides the signal via a control line 42 to actuate the head assembly 24 to position the servo head 26 laterally, and thereby to position the offset data head 28. The track following

20   servo thereby adjusts the lateral position of the servo head or the tape to maintain the servo head (or heads) at a desired lateral position with respect to the servo track (or tracks) such that the data heads are centered with respect to corresponding data tracks.

Although the linear track following servo system has been described in a tape environment with the servo read head offset from the data head, a linear track following servo may also be implemented in a disk drive environment, for example, with a

5 sector servo system in which the servo tracks are laid out in the same tracks as the data, and are read by the data heads, but the servo portions of the tracks are in sectors distributed around the disk and separating the data. In this case, the servo tracks may each encompass the width of several data tracks, but are

10 prerecorded at data frequencies readable by a data head, as is known to those of skill in the art.

An example of a track following servo system comprises a timing based servo system of the incorporated U.S. Patent No. 5,689,384. A timing based servo system is employed, for example,

15 with the Linear Tape Open (LTO) format, one example comprising the IBM LTO Ultrium magnetic tape drive and associated tape cartridge.

Referring to FIG. **2**, a linear servo track **27** comprises a sensible transition pattern, for example, of prerecorded magnetic

20 transitions forming a timing based servo pattern of a repeating cyclic periodic sequence of transitions of two different azimuthal orientations that extend laterally across the linear servo track. Those skilled in the art will recognize the dark vertical stripes represent magnetized areas of recorded magnetic

flux that extend across the width of a servo track **27**, and that

the edges of the stripes comprise flux transitions that are

detected to generate the servo read head signal. The transitions

have two magnetic polarities, one on each edge of a stripe. When

5 the servo read head crosses a transition of servo track **27**, e.g.,

along path **50**, it produces an analog signal pulse **52** whose

polarity is determined by the polarity of the transition. For

example, the servo read head may produce positive pulses on the

leading edge of each stripe (on encountering a stripe), and

10 negative pulses on the trailing edge (on leaving a stripe). To

reduce the chance for error, the servo control system times only

intervals between magnetic flux transitions having the same

polarity. As one example, only transition pulses generated by

the servo read head in moving across the leading edge of a stripe

15 are used, and transition pulses generated by moving across the

trailing edge of a stripe are ignored. Hence, herein, the term

"transition" refers to edges of stripes, or equivalent, that

result in the generation of signals having the same polarity.

As discussed above, the pattern may comprise transitions

20 slanted, or having an azimuthal orientation, in a first direction

with respect to the direction of the linear servo track,

alternating with transitions slanted, or having an azimuthal

orientation, in the opposite direction. Thus, as the medium is

moved with respect to the servo read head in the linear

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direction, the lateral positioning of the servo read head with respect to the timing based servo track is sensed based on a measure of time between two transitions having different azimuthal orientation **53**, called "A" intervals, as compared to

5 time between two transitions having parallel azimuthal orientation **54**, called "B" intervals. The incorporated U.S. Patent No. 5,689,384 discusses various types of transitions and their orientations.

The relative timing of the transitions read by the servo

10 read head varies linearly depending on the lateral position of the head. Thus, a number of parallel data tracks may be aligned with different lateral positions across the servo track.

Synchronization of the servo read head and decoder to the servo pattern may be accomplished by having two separate sets of

15 transitions, each set comprising a grouping of a different number of pairs of transitions, one set comprising a grouping having, for example, 4 pairs of transitions, and another set comprising a grouping having 5 pairs of transitions. Herein, "synchronization" refers to a determination of the location of a

20 sensed transition within the cyclic periodic sequence of transitions. In FIG. **2**, a pair of transitions may comprise transitions **55** and **56** in a grouping of 4 pairs, and may comprise transitions **57** and **58** in a grouping of 5 pairs. Thus, the lateral position of a servo read head with respect to the servo

track may comprise a measure of distance between two transitions

having different azimuthal orientation, e.g., between a first

transition **55** of a pair in one set and the other transition **56** of

the pair, this distance called the "A" distance. The servo read

5 head senses transitions in time which must be converted to

geometric distance to compute lateral position. The distance

between transitions having parallel orientation is independent of

lateral position. Parallel transitions are nominally written a

fixed distance apart by the servo writer, thus by comparing the

10 "A" timings **53** to the "B" timings **54** the geometric length of the

"A" pulse and hence the lateral position can be determined. Note

that the lateral position determined in this manner is

independent of tape speed in the readback device (as long as it

doesn't change during the time the "A" and "B" pulses are

15 measured).

Referring to FIG. **3**, in the prior art, the linear servo

track timing based servo pattern is generated by a servo writer

having two spaced apart write elements **60** and **61** of different

azimuthal orientations, forming the "A" distance. A drive moves

20 the linear data storage medium across the write elements along a

path illustrated by centerline **62** at a predetermined velocity,

and a source of timed pulses causes the write elements to write a

single pair of transitions for each pulse, such that the pattern

of pairs of transitions are written on the linear data storage medium.

In theory, the format is extendable to higher track pitches, wherein the data tracks are closer together. The "A" distance is
5 determined photolithographically, and is independent of the timing of the pulses or of the velocity of the servo writer drive.

However, the geometric "B" distance is dependent upon the precision of the velocity of the servo writer drive and the timed
10 pulses. For example, the write elements 60 and 61 would write the second pair of transitions as illustrated by dashed lines 64 and 65. Thus, the similar first transition 64 of another pair in another set of transitions may be misregistered with respect to the first transition, e.g., formed by write element 60, of the
15 pair in the one set. Hence, with a given pulse timing, the geometric length of the "B" transitions is strictly proportional to the velocity of tape in the drive of the servo writer. Servo writer velocity error introduces a servo position error to the servo track following system and results in data track
20 misregistration.

Referring to FIGS. 4 and 5, the present invention provides a more precise linear servo track timing based servo pattern, employing a servo writer having at least three spaced apart write elements, two of parallel azimuthal orientation, and at least one

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of a different azimuthal orientation than the two of parallel azimuthal orientation. Preferably, the write element of the different azimuthal orientation is located intermediate the two write elements of parallel azimuthal orientation.

5   In the embodiment of FIG. **4**, three write elements **70**, **71** and **72** are provided, two of the write elements, **70** and **72**, of parallel azimuthal orientation, and write element **71** of a different azimuthal orientation than the two of parallel azimuthal orientation, and located intermediate the two write

10 elements of parallel azimuthal orientation.

In the embodiment of FIG. **5**, four spaced apart write elements **80-83** are provided. Two write elements **80** and **82** are of parallel azimuthal orientation, and write elements **81** and **83** are of a different azimuthal orientation than the two of parallel

15 azimuthal orientation (and parallel to each other). One of the write elements of the different azimuthal orientation **81** is located intermediate the two write elements of parallel azimuthal orientation. Alternatively, the two write elements **81** and **83** may be considered to be of parallel azimuthal orientation, and write

20 elements **80** and **82** to be of a different azimuthal orientation, with write element **82** located intermediate the two write elements of parallel azimuthal orientation.

Referring to FIGS. **6A** and **6B**, linear servo track timing based servo pattern is generated by a servo writer energizing the

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write elements **70-72** of FIG. **4** as a drive moves the linear data storage medium across the write elements along a path illustrated by centerline **78**. A source of timed pulses causes the spaced apart write elements **70-72** to simultaneously write, such that the

5 transitions on the linear data storage medium correspond to the spaced apart write elements. For example, transitions **90, 91** and **92** on the linear data storage medium are written simultaneously and respectively correspond to the spaced apart write elements **70, 71** and **72**. A complete pattern of 5 transitions each is

10 represented by bracket **94**.

Thus, the spaced apart write elements **70-72** fix both the distance between transitions having different azimuthal orientation, the "A" distance, and the distance between transitions having parallel azimuthal orientation, the "B"

15 distance. Therefore, both the "A" and "B" timing are referenced to the same instant of servo writing, and the position error signal will be independent of servo write tape velocity. For example, simultaneously writing with spaced apart write elements **70** and **71** fixes both transitions **90** and **91** and fixes the "A"

20 distance **95** therebetween. Simultaneously writing with spaced apart write elements **70** and **72** fixes both transitions **90** and **92** and fixes the "B" distance **96** therebetween. Hence, simultaneously writing with the three spaced apart write elements

provides a more precise linear servo track timing based servo
pattern.

In one embodiment of the present invention, sets of timed
pulses are provided to the write elements, each set of pulses

5   writing a pattern of transitions, e.g., pattern **94** of
transitions, and spaces the sets of pulses to prevent overwriting
of one pattern of transitions by another, e.g., spacing a pattern
97 so as to prevent overwriting transitions of pattern **94**.

The illustration of FIG. **6B** represents one arrangement of

10 the transitions to provide synchronization of the repeated cyclic
periodic sequence of transitions, as "synchronization" is defined
above. Specifically, in the repeating cyclic periodic sequence
of transitions, the transitions having parallel azimuthal
orientation at one end of one pattern, e.g., transition **98** of

15 pattern **94**, continue with the transitions having parallel
azimuthal orientation at the opposite end of the next pattern,
e.g., transition **99** of pattern **97**. Thus, the continuing
transitions are combined to have a different number of
transitions than the remainder of the repeating cyclic periodic

20 sequence of transitions, thereby providing synchronization of the
repeating cyclic periodic sequence of transitions.

Referring to FIGS. **7A** and **7B**, linear servo track timing
based servo pattern is generated by a servo writer energizing the
write elements **80-83** of FIG. **5** as a drive moves the linear data

storage medium across the write elements along a path illustrated

by centerline **88**. A source of timed pulses causes the spaced

apart write elements **80-83** to simultaneously write, such that the

transitions on the linear data storage medium correspond to the

5 spaced apart write elements and are independent of servo writer

velocity. For example, transitions **100**, **101**, **102** and **103** on the

linear data storage medium are written simultaneously and

respectively correspond to the spaced apart write elements **80**,

81, **82** and **83**. A complete pattern of 5 transitions each is

10 represented by bracket **105**.

Thus, the spaced apart write elements **80-83** fix both the

distance between transitions having different azimuthal

orientation, the "A" distance, and the distance between

transitions having parallel azimuthal orientation, the "B"

15 distance. For example, simultaneously writing with spaced apart

write elements **80** and **81** fixes both transitions **100** and **101** and

fixes the "A" distance **106** therebetween. Simultaneously writing

with spaced apart write elements **80** and **82** fixes both transitions

100 and **102** and fixes the "B" distance **107** therebetween.

20 Similarly, simultaneously writing with spaced apart write

elements **82** and **83** fixes both transitions **102** and **103** and fixes

the "A" distance **108** therebetween. Simultaneously writing with

spaced apart write elements **81** and **83** fixes both transitions **101**

and **103** and fixes the "B" distance **109** therebetween. Hence,
simultaneously writing with the four spaced apart write elements
provides a more precise linear servo track timing based servo
pattern.

5   An alternative synchronization embodiment is provided with
the arrangement of FIGS. **5** and **7B**, employing an even number of
the write elements **80-83**. The source of timed pulses provides a
different number of pulses to the write elements **80-83** for each
of alternating sets of pulses. Thus, the write elements **80-83**
10 are pulsed to write alternating patterns with different numbers
of transitions, thereby providing synchronization of the
repeating cyclic periodic sequence of transitions. For example,
pattern **105** is written with 5 pulses, writing 5 sets of
transitions, and alternating pattern **115** is written with 4
15 pulses, writing 4 sets of transitions, thereby providing the
synchronization.

Referring to FIGS. **8A** and **8B**, a linear servo track timing
based servo pattern is generated which duplicates the pattern
illustrated in FIG. **2**, but with fixed "A" and fixed "B"
20 distances. The servo pattern is produced by a servo writer in
which the pulse source is separately coupled to the write
elements **80** and **81**, and to write elements **82** and **83** of FIG. **5**, as
will be discussed.

A drive moves the linear data storage medium across the write elements along a path illustrated by centerline **88**. As illustrated in FIG. **8B**, a source of timed pulses provides pulses to all of the write elements to cause the spaced apart write

5 elements **80-83** to simultaneously write 4 transitions, such that the transitions on the linear data storage medium correspond to the spaced apart write elements. For example, in a pattern of transitions represented by bracket **118**, transitions **120**, **121**, **122** and **123** on the linear data storage medium are written

10 simultaneously and respectively correspond to the spaced apart write elements **80**, **81**, **82** and **83**.

Thus, the spaced apart write elements **80-83** fix both the distance between transitions having different azimuthal orientation, the "A" distance, and the distance between

15 transitions having parallel azimuthal orientation, the "B" distance. For example, simultaneously writing with spaced apart write elements **80** and **81** fixes both transitions **120** and **121** and fixes the "A" distance **126** therebetween. Simultaneously writing with spaced apart write elements **80** and **82** fixes both transitions

20 **120** and **122** and fixes the "B" distance **127** therebetween. The distances may also be fixed as discussed with respect to write elements **82** and **83** for an "A" distance, and write elements **81** and **83** for a "B" distance as discussed above with respect to FIG. **7B**. Hence, simultaneously writing with the four spaced apart write

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elements, or with three of the four write elements, provides a
more precise linear servo track timing based servo pattern.

As a further alternative synchronization embodiment, the
source of timed pulses is coupled to two adjacent write elements
5 of FIG. **5**, and separately coupled to the other write elements.
Thus, in the arrangement of FIGS. **5** and **8B**, the source of timed
pulses is coupled to two adjacent write elements **80** and **81** and
separately coupled to the other write elements **82** and **83**. The
source of timed pulses provides one set of timed pulses to all of
10 the spaced apart write elements **80-83** as discussed above to
simultaneously write to fix the distances between the
transitions, here called "first" timed pulses, and additionally
provides at least one additional timed pulse to only the two
adjacent write elements **80** and **81**, herein called a "second" timed
15 pulse, to write different numbers of transitions within the
pattern for synchronization. For example, one additional timed
pulse is provided to write elements **80** and **81** to write
transitions **128** and **129**, thereby providing a different number of
transitions to that portion of the pattern, and providing
20 synchronization of the repeating cyclic periodic sequence of
transitions. The one skilled in the art, it will be clear that
by separately coupling the pair of write elements **80, 81** and the
pair of write elements **82, 83** in FIG. **5**, this servo writer head
is able to write any pattern that can be written with the prior

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art servo writer head in FIG. **3**, but with the simultaneous

pulsing, is ablve to provide the ability to precisely replicate

the pattern of 4 transitions built into the servo writer head.

A multiple gap servo write head **400** is illustrated in FIG.

5 **9**, based on the write head of the incorporated U.S. Patent No.

5,689,384. The illustrated head comprises a ferrite ring **402**

with a patterned NiFe (or other suitable magnetic material) pole

piece region **404**. Two ferrite blocks **406**, **408** form the bulk of

the write head and are separated by a glass spacer **411**.

10 Cross-slots **412** are cut into the head to remove included air when

the head is in operation with magnetic tape. The pole piece

region **404** is patterned in the shape of the desired servo

patterns **414** of write elements by photolithographic techniques as

is known to those of skill in the art. A coil **420** is wound

15 around one of the ferrite blocks **408** through a wiring slot **422** to

complete the head.

FIG. **10** illustrates an embodiment of a process of producing

a magnetic tape **504** having the servo patterns discussed above

using an embodiment of a servo writer **502** in accordance with the

20 present invention. Alternative embodiments of a servo writer **502**

are illustrated in FIGS. **11-13**.

A drive comprising supply reel **520**, take-up reel **522** and

rolls **505** move magnetic tape **504** in the direction of arrow **512**

across a write head **510** having the patterned write elements. The

write head is such as that comprising head **400** illustrated in

FIG. **9**, with the write elements of FIG. **4** or of FIG. **5**. As the

tape **504** is moved across the servo write head **510**, pulses are

5 provided to the write elements as discussed in the incorporated

U.S. Patent No. 5,689,384 to energize the write elements and

record the servo pattern on the tape. The pattern generator **516**

provides the pattern pulses to a pulse generator **518** which

energizes the head in accordance with the pattern pulses. A

10 servo read head **524** reads the recorded servo pattern and provides

a servo signal to a preamplifier **526** for providing an amplified

version of the servo signal to a pattern verifier **528** for

verifying the servo pattern. If any errors are found that make

the servo pattern of unacceptable quality, the verifier operates

15 a bad-tape marking head to place a magnetic mark on the tape **504**

so that bad sections of tape are not loaded into a tape

cartridge.

FIG. **11** illustrates an embodiment of the servo writer

employing the write elements **70-72** of FIG. **4** in the write head

20 **510**. Pattern generator **516** operates pulse generator **518** to

provide pulses causing the spaced apart write elements **70-72** to

simultaneously write, such that the transitions, e.g.,

transitions **90**, **91** and **92** of FIG. **6B**, are written simultaneously,

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and, with additional simultaneously written transitions, form a complete pattern of 5 transitions each, as is represented by bracket **94**.

Thus, the spaced apart write elements **70-72** fix both the distance between transitions having different azimuthal orientation, the "A" distance **95**, and the distance between transitions having parallel azimuthal orientation, the "B" distance **96**.

As discussed above, the pulses are sets of timed pulses provided to the write elements, each set of pulses writing a pattern of transitions, e.g., pattern **94** of transitions, and spaced to prevent overwriting of one pattern of transitions by another, e.g., spacing a pattern **97** so as to prevent overwriting transitions of pattern **94**.

The timing of the pulses provided by the pattern generator **516** and pulse generator **518** additionally provide synchronization, as described above. Specifically, in FIG. **6B**, the transitions having parallel azimuthal orientation at one end of one pattern, e.g., transition **98** of pattern **94**, continue with the transitions having parallel azimuthal orientation at the opposite end of the next pattern, e.g., transition **99** of pattern **97**. Thus, the continuing transitions are combined to have a different number of transitions than the remainder of the repeating cyclic periodic

sequence of transitions, thereby providing synchronization of the repeating cyclic periodic sequence of transitions.

FIG. 12 illustrates an embodiment of the servo writer employing the write elements 80-83 of FIG. 5 in the write head

5   510.   Pattern generator 516 operates pulse generator 518 to provide pulses causing the spaced apart write elements 80-83 to simultaneously write, such that the transitions, e.g., transitions 100, 101, 102 and 103 of FIG. 7B, are written simultaneously, and, with additional simultaneously written

10   transitions, form a complete pattern of 5 transitions each is represented by bracket 105.

Thus, the spaced apart write elements 80-83 fix both the distance between transitions having different azimuthal orientation, the "A" distance 106, 108, and the distance between

15   transitions having parallel azimuthal orientation, the "B" distance 107, 109.   Hence, simultaneously writing with the four spaced apart write elements provides a more precise linear servo track timing based servo pattern.

Referring to FIGS. 12, 5 and 7B, synchronization is provided

20   by pattern generator 516 and pulse generator 518 providing a different number of pulses to the write elements 80-83 for each of alternating sets of pulses.   Thus, the write elements 80-83 are pulsed to write alternating patterns with different numbers of transitions, thereby providing synchronization of the

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repeating cyclic periodic sequence of transitions. For example,

pattern **105** is written with 5 pulses, writing 5 sets of

transitions, and alternating pattern **115** is written with 4

pulses, writing 4 sets of transitions, thereby providing the

5 synchronization. Further, as discussed above, the timing of the

pulses is such as to space sets of transitions to prevent

overwriting.

FIG. **13** illustrates an embodiment of the servo writer

employing the write elements **80-83** of FIG. **5** in the write head

10 **510**, in which the pattern generator **516** is separately coupled to

pulse generator **518** and to pulse generator **519**. Thus, the

source of pulses is separately coupled to the write elements **80**

and **81**, and to write elements **82** and **83**. The write head **510** is a

single fixed head with two areas in which write elements are

15 located and which are separately engerized, as is understood by

those of skill in the art.

Additionally referring to FIG. **8B**, as a drive moves the

magnetic tape **504** across the write elements, the source of timed

pulses provides pulses to all of the write elements to cause the

20 spaced apart write elements **80-83** to simultaneously write 4

transitions, such that the transitions on the linear data storage

medium correspond to the spaced apart write elements. For

example, in the pattern of transitions represented by bracket

118, transitions **120**, **121**, **122** and **123** are written simultaneously

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and respectively correspond to the spaced apart write elements

80, 81, 82 and **83.** Thus, the spaced apart write elements **80-83**

fix both the distance between transitions having different

azimuthal orientation, the "A" distance **126,** and the distance

5 between transitions having parallel azimuthal orientation, the

"B" distance **127.**

Coupling the source of timed pulses to two adjacent write

elements **80** and **81** of FIG. **5,** and separately coupling the other

write elements **82** and **83** allows the pattern to be synchronized

10 and appear similar to the pattern of FIG. **2.** As discussed above,

pattern generator **516** and pulse generators **518** and **519** provide

first timed pulses to all of the spaced apart write elements

80-83 as discussed above, to simultaneously write the transitions

to fix the distances between the transitions. To provide

15 synchronization, pattern generator **518** operates only pulse

generator **518** to provide at least one second timed pulse to only

the two adjacent write elements **80** and **81** to write different

numbers of the transitions within the pattern. Thus, additional

transitions are written by less than all of the write elements.

20 This adds transitions to a portion of the pattern that are fewer

in number than the simultaneously written transitions. For

example, one second timed pulse is provided to write elements **80**

and **81** to write transitions **128** and **129,** thereby providing a

different number of transitions to that portion of the pattern,

and providing synchronization of the repeating cyclic periodic

sequence of transitions. Again, as discussed above, the timing

of the pulses is such as to space sets of transitions to prevent

overwriting.

5   Those of skill in the art understand that alternative

arrangements of the pattern generator and pulse generator(s) and

alternative timings of the timed pulses may be employed with

alternative arrangements of the write elements to produce

patterns of transitions which also fix the "A" distances and the

10 "B" distances.

FIG. **14** illustrates an example of a tape drive system **10**

employing track following servoing which may be employed with a

tape having a linear servo track timing based servo pattern of

the present invention. The tape drive **12** accepts a tape

15 cartridge **14** and is coupled to a host system **16** by a coupling **18**.

The tape cartridge comprises a housing **19** containing a length of

magnetic tape **20**. The tape drive **12** is arranged for use with a

length of magnetic tape having a linear servo track timing based

servo pattern. The tape drive reads the servo information as the

20 servo read head traces a path along the servo pattern, and

generates a position signal to control the position of a data

head, such as is discussed with respect to FIG. **1**.

In the servo pattern, the "A" distances and the "B" distances are fixed in accordance with the present invention, thereby providing a more precise linear servo track timing based servo pattern.

5   While the preferred embodiments of the present invention have been illustrated in detail, it should be apparent that modifications and adaptations to those embodiments may occur to one skilled in the art without departing from the scope of the present invention as set forth in the following claims.

10   We claim: